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NEW COUPLING SCHEME IN THE INTERACTING BOSON–FERMION MODEL: O(6) SPECTRA IN ODD-A NUCLEI

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We suggest that a new coupling scheme, based on the O(6) boson symmetry, may be useful in describing the spectra of odd-A nuclei towards the end of major shells. We describe the main properties of this scheme and show one example of it.

In this letter we report on the results of some calculations which suggest the possibility of a new coupling scheme in odd-A nuclei. This coupling scheme may be useful in describing odd-A nuclei towards the end of the major neutron shells, such as those in the Os–Ir–Pt–Au region and in the I–Ba–Cs–Ce region, where the corresponding even–even nuclei display O(6)-like spectra. Our discussion will be based on the interacting boson–fermion model of odd-A nuclei recently proposed by us [1]. However, a similar discussion could be carried on within the framework of the Bohr–Mottelson description [2].

In the interacting boson–fermion model, the total hamiltonian, H, of an odd-A nucleus is written as $H = H_B + H_F + V_{BF}$. Here H_B is the boson part [3] of H, $H_F = \Sigma_{jm} \epsilon_j a_{jm}^\dagger a_{jm}$ is its fermion part, and V_{BF} denotes the boson–fermion interaction. In ref. [1], it was suggested that three terms may dominate the structure of the spectra in odd-A nuclei: effective monopole and quadrupole interactions, and exchange term [1]. Correspondingly, V_{BF} may be written as

$$V_{BF} = A[(s^\dagger \times s)^{(0)} \times (a_j^\dagger \times \tilde{a}_j)^{(0)}]^{(0)}$$
$$+ \Gamma\{[(d^\dagger \times s + s^\dagger \times \tilde{d})^{(2)} + \chi(d^\dagger \times \tilde{d})^{(2)}]$$
$$\times (a_j^\dagger \times \tilde{a}_j)^{(2)}\}^{(0)}$$
$$- \Lambda\!: [(\tilde{d} \times a_j^\dagger)^{(j)} \times (d^\dagger \times \tilde{a}_j)^{(j)}]^{(0)}: , \qquad (1)$$

where we have used the same notation as in ref. [1] and considered once more only the case of one single particle level, j.

Within the framework of this approach, simple coupling schemes in odd-A nuclei will emerge, whenever the hamiltonian H_B possesses one of its three possible dynamical symmetries SU(5) [4], SU(3) [5] and SO(6) [6]. As was shown in ref. [1], the dynamical symmetry SU(3) leads to the Nilsson coupling scheme. This scheme, first derived within the framework of the Bohr–Mottelson description [7], has played a major role in the description of odd-A nuclei towards the middle of major shells. The purpose of this letter is to discuss a new coupling scheme, based on the O(6) symmetry. In doing this, we were stimulated by the observation that the O(6) symmetry may play an important role in the spectra of nuclei towards the end of the major shells [8].

In order to show the important properties of the new coupling scheme, we return to $H = H_B + H_F + V_{BF}$, take as H_B the O(6) hamiltonian of ref. [6], and consider as an example the coupling of a particle with $j = 9/2$. Furthermore, to begin with, we set $A = 0$ and $\Lambda = 0$ in V_{BF}. We are thus left with only the second term in (1). This term contains the boson quadrupole operator $Q_B^{(2)} = (d^\dagger \times s + s^\dagger \times \tilde{d})^{(2)} + \chi(d^\dagger \times \tilde{d})^{(2)}$. But, in the limit of an O(6) symmetry, Q_B must be a generator of O(6) [6]. Thus $\chi = 0$, and V_{BF} becomes

$$V'_{\mathrm{BF}} = \Gamma[(d^\dagger \times s + s^\dagger \times \tilde{d})^{(2)} \times (a_j^\dagger \times \tilde{a}_j)^{(2)}]^{(0)}. \quad (2)$$

With this V'_{BF}, we now diagonalize H. The resulting low-lying spectrum is shown in fig. 1. Its structure appears to be very regular and simple with several families (or bands) of states connected by large E2 transitions. These bands have a "triangular"-like structure which resembles neither a Nilsson structure nor a weak-coupling structure. Nonetheless, as in these two cases, the entire low lying spectrum can be constructed by means of simple rules which we now list:

(i) There are first three bands, denoted by T_0, T_2 and T_4 in fig. 1; the lowest angular momentum in these bands is 9/2, 5/2 and 1/2, respectively. (The corresponding rule for a single particle level with angular momentum j is that there are $\hat{n}$ bands, $T'_{\hat{n}}$, with lowest angular momentum given by $\hat{j} = j - \hat{n}$, $\hat{n} = 0, 2, 4, \ldots$ $(\hat{j} > 0)$.)

(ii) At higher excitation energy there are two additional bands, denoted by R_1 and R_3 in fig. 1; the lowest angular momentum in these bands is 7/2 and 3/2, respectively. (The corresponding rule for a single particle level with angular momentum j is that there are $\hat{n}$ bands $R_{\hat{n}}$, with lowest angular momentum given by $\hat{j} = j - \hat{n}$, $\hat{n} = 1, 3, 5, \ldots$ $(\hat{j} > 0)$.)

(iii) Within each band states can be classified by a quantum number $\hat{\tau}$ ($\hat{\tau} = 0, 1, 2, \ldots$); the bands stop at some value $\hat{\tau} = \hat{\tau}_{\max}$ related to the number of bosons in the core; the angular momenta J contained in each $\hat{\tau}$ multiplet are given by the rule

$$J = \hat{j} + 2\hat{\tau}, \hat{j} + 2\hat{\tau} - 1, \ldots, \hat{j} + \hat{\tau}\ . \quad (3)$$

For example, for the band T_0, this gives: $\hat{\tau} = 0$, $J = 9/2$; $\hat{\tau} = 1$, $J = 13/2, 11/2$; $\hat{\tau} = 2$, $J = 17/2, 15/2, 13/2$; etc.

(iv) The energy levels are approximately given by the formula

$$E(\hat{n}, \hat{\tau}, J) = \hat{A}\{\hat{n}\} + \hat{B}\hat{\tau}(\hat{\tau} + 3) + \hat{C}J(J+1)\,, \quad (4)$$

where $\hat{A}\{\hat{n}\}$ depends on $\hat{n} = 0, 1, 2, 3 \ldots$ and $\hat{B}$ and $\hat{C}$ are appropriate constants; large deviations from this formula appear only in the band with $\hat{j} = 1/2$.

Since O(6)-like spectra have been observed in even-even nuclei in the platinum region [8], we may expect that the coupling scheme discussed here may be found in the spectra of odd-A nuclei in this region. An example [9] is shown in fig. 2. It would be interesting to investigate in detail other examples of this coupling scheme.

In conclusion, we have suggested a new possible coupling scheme in odd-A nuclei, and discussed in de-

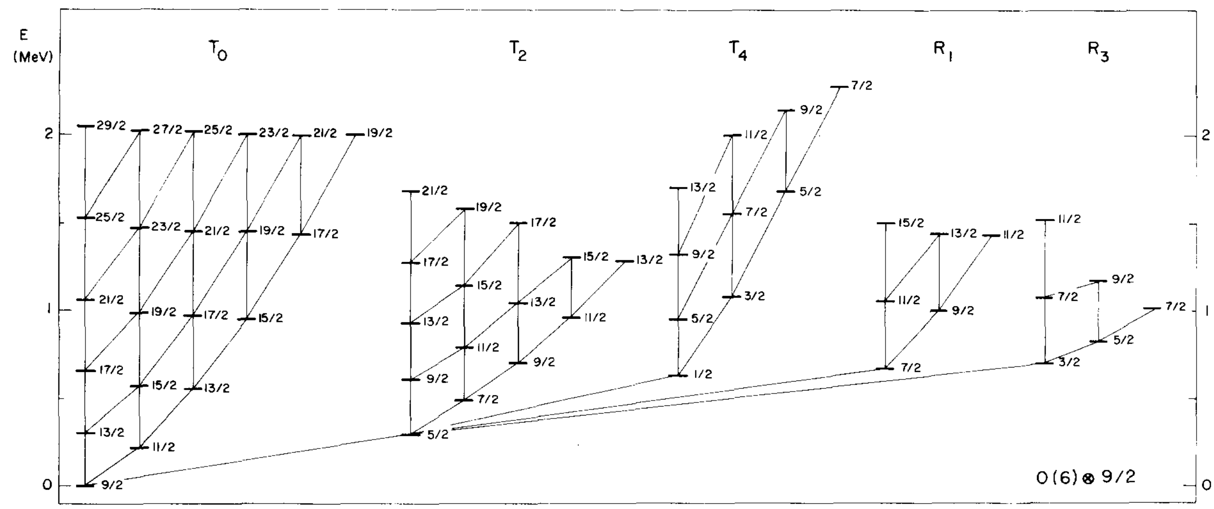

Fig. 1. Typical O(6)-like spectrum in an odd-A nucleus. The number of bosons in $N = 6$, the odd particle has $j = 9/2$ and the energy levels are calculated by diagonalizing the hamiltonian [6] $H = \bar{A}P_6 + \bar{B}C_5 + \bar{C}C_3 + \Gamma\{d^\dagger \times s + s^\dagger \times \tilde{d})^{(2)} \times (a_j^\dagger \times \tilde{a}_j)^{(2)}\}^{(0)}$, with $\bar{A} = 200$ keV, $\bar{B} = 225$ keV, $\bar{C} = 0$ and $\Gamma = 500$ keV. The lines connecting the levels denote large E2 transitions.

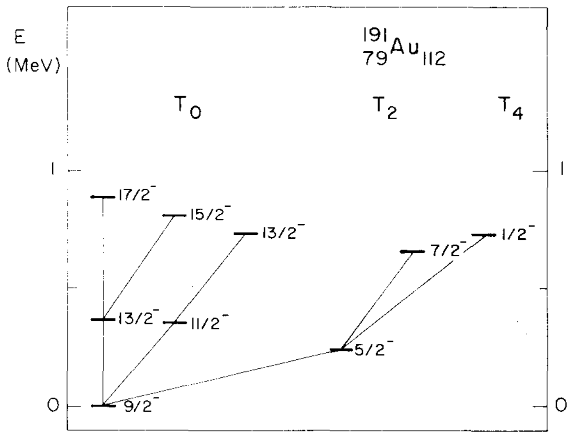

Fig. 2. The experimental spectrum built on the $h_{9/2}$ proton configuration in $^{191}_{79}Au_{112}$. Note the occurrence of the multiplets $13/2^-$, $11/2^-$; $5/2^-$and $17/2^-$, $15/2^-$, $13/2^-$; $7/2^-$; $1/2^-$. In order to complete the second multiplet a state with $J = 9/2^-$ should be found around the energy of the $15/2^-$ state

tail the simple case of a single particle with $j = 9/2$ and $A = 0$, $\Lambda = 0$. We note that the important properties of this coupling scheme persist even when $A \neq 0$ and $\Lambda \neq 0$. The monopole term, A, does not appear to introduce any new feature, while the effect of the exchange term, Λ, is that of displacing some of the bands relative to the others (for example, the R-bands are moved down relative to the T-bands), while leaving their structure unchanged. Finally, it would be interesting to investigate in detail the connection between the coupling scheme presented here and its counterpart in the Bohr–Mottelson description. Since, as shown recently by Meyer-ter-Vehn [10], the O(6) limit, corresponds, within certain approximations, to the γ-unstable solution of Wilets and Jean [11] which, in turn, shares some properties with the triaxial rotor model [12], some of the features of the present coupling scheme should also appear both in the γ-unstable [12] and trixial rotor [14] plus particle calculations.

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